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embodiment

diagram of a

FIG. 6 is a schematic diagram of a preferred embodiment of a means for increasing dialysate flow velocity through the dialyzer without increasing the dialysate flow rate.

5 FIG. 7 shows a block diagram of a computer system used in the preferred embodiment.

FIG. 8 shows a touch screen display used in the preferred embodiment.

10 FIG. 9 shows the touch screen of FIG. 8 with a calculator window for data entry.

FIG. 10 shows a profile entry screen used in the preferred embodiment.

FIG. 11 shows a programming screen used in the preferred embodiment.

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#### DETAILED DESCRIPTION

##### Hydraulic Circuit

C 20 A hydraulic circuit 10 representing a preferred embodiment of an improved hemodialysis machine according to the present invention is illustrated in FIG. 1A and 1B. The hydraulic circuit 10 is comprised of the following principal components: an incoming water pressure regulator 12, a water on/off valve 14, a heat exchanger 16, a heater 18, a safety thermostat 20, an "A" concentrate pump 22, a supply valve 24, an air gap chamber 26, an "A" rinse fitting 28, a "B" rinse fitting 30, a deaeration sprayer 32, an air removal pump 34, a vented air trap 36, an "A" conductivity probe 38, a "B" concentrate pump 40, a supply pump 42, a "B" mix chamber 30 44, a "B" conductivity probe 46, a dialysate filter 48, a supply regulator 50, an input pressure equalizer 52, a flow equalizer 54, an output pressure equalizer 56, end-of-stroke sensors 59, a dialysate conductivity probe 60, a pre-dialyzer flow sensor 62, a dialysate pressure 35 transducer 64, a bypass valve 66, a dialysate sample port 68, a post-dialyzer flow sensor 70, a dialysate pressure pump 72, a UF removal regulator 74, a UF flow meter 76, a blood-leak detector 78, and a rinse valve 80. The

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mentioned components are interconnected as shown in

FIGS. 1A and 1B

interconnected

The incoming water pressure regulator 12 is coupled to a pressurized water source 82 and reduces and stabilizes the water supply pressure to a level of about 20 psig.

The water on/off valve 14 opens when machine power is on, thereby allowing water to flow from the source 82 into the hydraulic circuit 10. When the machine power is off, the water on/off valve 14 is closed.

The heat exchanger 16 transfers heat from "spent" or effluent dialysate, passing through conduit 84, to the cooler incoming water passing through conduit 86 as these two liquids pass countercurrently through separate but adjacent compartments in the heat exchanger 16. In this way, the incoming water is warmed, which reduces the amount of heat energy that must be supplied to the water by the heater 18.

The heater 18 further warms the incoming water to a suitable temperature for hemodialysis, which is about 38°C. A typical heater 18 is a resistance type known in the art, rated at about 1500 watts. The heater 18 includes a downstream thermistor 20 or analogous temperature-sensing device. A thermistor as known in the art is essentially a temperature-sensitive resistor which experiences a change in electrical resistance that is inversely proportional to a corresponding change in temperature. The thermistor 20 is coupled to the machine's microprocessor (not shown in FIG. 1A) which utilizes signals from the thermistor for turning the heater 18 on and off as required to maintain the water temperature at the proper level.

The "A" concentrate pump 22 propels either "acid" or "acetate" concentrate as known in the art from a container thereof 88 into the air gap chamber 26. The "A" concentrate pump 22 is a fixed-volume cam-driven pump. A stepper motor 90 calibratable to rotate a precise number of rotations per minute is preferably used to drive the

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## conductivity

Before describing the hydraulic circuit any further, it is appropriate to briefly describe the flow equalizer 54. The flow equalizer 54 comprises a first chamber 126 and a second chamber 128 of substantially equal volume. Each chamber 126, 128 is comprised of two compartments, one termed a "pre-dialyzer" or "pre" compartment 130, 132 and the other a "post-dialyzer" or "post" compartment 134, 136. Each pair of opposing "pre" and "post" chambers is separated by a flexible diaphragm 138, 140. Solenoid-actuated valves 142-149 control the filling and emptying of each compartment. In general, each compartment 130, 132, 134, 136 is completely filled before its contents are discharged. Also, the "pre" compartments 130, 132 are alternately filled and discharged and the "post" compartments 134, 136 are alternately filled and discharged. Also, filling a "pre" compartment 130, 132 causes a corresponding discharge of an opposing "post" compartment 134, 136, respectively. The "pre" compartments 130, 132 alternately fill from the supply pump 42 and alternately discharge to the dialyzer. The "post" compartments 134, 136 alternately fill with "spent" dialysate returning from the dialyzer and discharge the spent dialysate to a drain line 150. For example, dialysate from the supply pump 42 enters the "pre" compartment 132, thereby displacing the diaphragm 140 in FIG. 1b to the right, causing the "post" compartment 136 to empty. Simultaneously, "post" compartment 134 fills while "pre" compartment 130 empties.

The flow equalizer 54 operates via a four-phase cycle. In the first phase, valves 142, 145, 147, and 148

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The supply pump 42 delivers dialysate at a maximum regulated pressure of 12.5 psig and at a flow rate approximately 50 mL/min higher than the dialysate flow rate set by the operator using the touch screen.

5 The dialysate filter 48 is used to occlude downstream passage of particulate foreign material into the flow equalizer 54. The supply regulator 50 is adjusted to an output pressure of approximately 16 psig. Whenever the "pre" and "post" compartments of the flow  
10 equalizer 54 reach the end of a fill cycle during phases 1 or 3, pressure builds up in the loop 152. As the pressure increases to about 16 psig, the supply regulator 50 opens sufficiently to pass the dialysate output of the supply pump 42 through the loop 152 until the next phase 1 or 3.

15 The input pressure equalizer 52 equilibrates hydraulic pressures at the inlets 155 of the flow equalizer 54 so that the compartments 130, 132, 134, 136 fill at the same rate. Likewise, the output pressure equalizer 56 equilibrates hydraulic pressures at the  
20 outlets 156 of the flow equalizer 54. The input and output pressure equalizers are discussed in greater detail hereinbelow.

The input pressure equalizer 52 also automatically equilibrates the pressure of the dialysate  
25 flowing through the downstream lines 158, 160 with the pressure of dialysate at the flow equalizer inlets 154. Whenever the pressure at the flow equalizer inlets 154 exceeds the pressure generated by the dialysate pressure pump 72, the input pressure equalizer 52 restricts the  
30 flow of dialysate in lines 158, 160. Such equilibration of pressures allows both chambers 126, 128 in the flow equalizer 54 to be filled at identical rates.

End-of-stroke sensors 162, 164 are provided at the outlets 156 of the output pressure equalizer. The  
35 end-of-stroke sensors 162, 164 verify when the flow equalizer compartments have reached the end of a fill cycle (end of stroke). When the compartments are full, the end-of-stroke sensors 162, 164 send a no-flow signal

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The dialysate conductivity probe 60 measures the conductivity of the dialysate before it enters the dialyzer. The machine's microprocessor compares the measured conductivity with an expected conductivity value (discussed in detail hereinbelow) based upon concentrate formulation information entered by the operator using the touch screen. If the measured dialysate conductivity is excessively above or below the expected conductivity value, the machine's microprocessor activates a conductivity alarm. Also, the bypass valve 66 is triggered during a conductivity alarm to divert dialysate away from the dialyzer through conduit 166.

15 The dialysate conductivity probe 60 includes a thermistor 168 which allows temperature compensation of the conductivity reading. The electronic signal from the thermistor 168 is also utilized to provide a dialysate temperature display on the machine's touch screen as well as primary high and low temperature alarm limits. The dialysate conductivity as measured by the conductivity probe 60 is also displayed on the machine's touch screen.

The dialysate flow sensor 62 includes a self-heating variable thermistor as well as a reference thermistor (not shown in FIG. 1A but discussed in detail hereinbelow). The dialysate flow sensor 62 is used mainly as a bypass monitor. Whenever the machine is in bypass, the resulting lack of dialysate flow past the flow sensor 62 serves as a verification that the bypass valve 66 is functioning correctly.

The dialysate pressure transducer 64 senses dialysate pressure and converts the pressure reading into an analog signal proportional to the dialysate pressure. The analog signal is utilized by the machine's microprocessor as the basis for a dialysate pressure display on the touch screen, pressure alarms, and other dialysate control functions (not shown in FIG. 1).

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The bypass valve 56 protects the hemodialysis patient in the event of a temperature or conductivity alarm by diverting dialysate flow away from the dialyzer. The bypass valve 56 is a three-way solenoid valve which, when triggered, occludes the conduit 170 leading to the dialyzer and shunts the dialysate flow through conduit 166 to a location 172 downstream of the dialyzer.

The dialysate sample port 68 is an appliance which allows the operator to obtain a sample of the dialysate using a syringe for independent testing.

A second dialysate flow sensor 70 is located in the post-dialyzer ("venous") line 174. The second flow sensor 70 is constructed similarly to the first flow sensor 62 and is discussed in detail hereinbelow. The second flow sensor 70 is utilized for checking the accuracy of the machine's ultrafiltration capability.

The dialysate pressure pump 72 is situated downstream of the dialyzer. An accompanying recirculation loop comprising lines 158, 160 conducts effluent dialysate to the inlet pressure equalizer 52. The recirculation loop 158, 160 thereby helps equilibrate pressure differences that might otherwise be transmitted to the flow equalizer 54 and also serves as a source of hydraulic pressure sufficient to fill the UF flow meter 76 when demanded thereby.

The dialysate pressure pump 72 circulates dialysate at a constant flow rate of 1500 mL/min through the recirculation loop 158, 160 without affecting the overall dialysate flow rate through the hydraulic circuit 10. As a result, the dialysate pressure pump 72 is usable to adjust pressure differences across the dialyzer membrane.

As long as the dialysate pressure pump 72 receives an adequate volume of dialysate for pumping, the flow dynamics of dialysate through the hydraulic circuit 10 are unaffected. However, should liquid be removed from the recirculation loop 158, 160, the dialysate pressure pump will attempt to replace that lost volume by demanding

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more volume  
the  
volume from the dialyzer. Since the flow equalizer  
54 maintains volumetric constancy of dialysate passing to  
and from the dialyzer, the only fluid available to replace  
any fluid lost from the loop 158, 160 must come from the  
5 dialyzer itself. Hence, by precisely controlling the  
amount of liquid removed from the recirculation loop 158,  
160 (using the UF flow meter 76), the operator can  
precisely control the amount of liquid that must be  
removed from the hemodialysis patient via the dialyzer.

10 Since the dialysate pumped by the dialysate  
pressure pump 72 has a partially restricted flow, a  
sufficient pressure is thereby provided at the input of  
the UF removal regulator 74. The UF removal regulator 74  
regulates hydraulic pressure at the input 178 of the UF  
15 flow meter 76.

The UF flow meter 76 is comprised of a chamber  
180 separated into two subcompartments 182, 184 via a  
diaphragm 186. Each subcompartment 182, 184 has a  
corresponding valve 188, 190, respectively, associated  
20 therewith. Either subcompartment 182, 184 of the UF flow  
meter 76 can only fill when the corresponding valve 188,  
190 is opened. Whenever a first subcompartment 182 is  
filling, the opposing second compartment 184 is emptying  
its contents to a drain line 192. The rate of UF removal  
25 through the UF flow meter 76 is governed by the rate at  
which the corresponding valves 188, 190 are alternately  
opened and closed.

Whenever liquid leaves the recirculation loop  
158, 160 through the UF flow meter 76, correspondingly  
30 less liquid is recirculated through the recirculation loop  
158, 160. This causes a corresponding "starvation" at the  
input 172 of the dialysate pressure pump 72 which  
generates a corresponding decrease in dialysate pressure  
in the dialyzer. The decreased dialysate pressure causes  
35 a volume of liquid to be removed from the patient that is  
equal to the volume of liquid removed from the  
recirculation loop 158, 160 via the UF flow meter 76.  
These volumes will be equal so long as the dialyzer has an

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### ultrafiltration

ultrafiltration capability sufficient to remove said volume from the patient at the desired rate.

Effluent dialysate expelled from the flow equalizer 54 passes through and is monitored for the presence of blood by the blood-leak detector 78. The blood-leak detector 78, discussed in further detail hereinbelow, comprises a light source 194 and a photocell 196 which monitors light transmitted through the effluent dialysate solution passing therethrough. If blood leaks through the dialyzer membrane from the patient into the dialysate, the dialysate passing through the blood-leak detector 78 will absorb a portion of the light passing therethrough. The corresponding decrease in the amount of light reaching the photocell 196, if the decrease is excessive, triggers a blood-leak alarm by the machine.

Effluent dialysate from the blood-leak detector 78 is routed through conduit 84 to the heat exchanger 16, then to a drain 198.

The rinse valve 80 allows the UF flow meter 76 to remove rinse water from the recirculation loop 158, 160 at a rate of about 4 L/h. Such rinsing ensures an adequate flushing of the recirculation loop 158, 160 and UF flow meter 76. However, since liquid is removed from the loop 158, 160 at a relatively high rate during rinse, the rinse valve 80 also allows an equivalent volume of liquid to be added back to the loop 158, 160.

### User Interface

In the preferred embodiment, a touch screen user interface is employed.

Touch screens are known in the art and are commercially available from a number of sources, including Elographics West of San Diego, Cal. The use of touch screens in user interface applications for medical equipment is also known, as shown for example in US Patents 4,974,599 and 4,898,578, the disclosures of which are incorporated herein by reference.

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"Patents 4,974,599 and 4,898,578" .. "

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pressure

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pressure and TMP. MENUS replaces the buttons on the right hand side of the display with additional buttons corresponding to additional control functions, while maintaining the displayed parameters elsewhere on the screen. RINSE initiates the rinse mode, provided the interlocks are met. MUTE silences most audio alarms for 100 seconds. Additional buttons can appear in this part of the screen and are detailed in the Reference Section of Appendix A. Button locations are reprogrammable and can have multiple legends associated with them. Also, their positions on the touch screen can be varied by reprogramming.

If it is desired to change one of the displayed parameters, such as the heparin pump rate, the operator simply touches the corresponding indicator. A calculator-like keyboard then pops up in a window superimposed on the display, as shown in FIG. 9. On this keyboard, the user can enter the new value for the selected parameter. Once the desired parameter is entered in this fashion, the operator presses ENTER on the calculator display and the calculator display disappears. The revised parameter is substituted in the corresponding indicator (with its border highlighted) and the user is prompted, through a button that appears at the lower right hand side of the screen, to verify the entered change. If the VERIFY button is not touched shortly after displayed, the VERIFY button disappears and the machine continues with its previous parameter. If timely verified, the change takes effect. In the preferred embodiment, the user has between one and five seconds to verify the parameter.

Some parameters are not susceptible to representation by a single number displayed in a parameter window. Exemplary are parameters that are programmed to change over time (so-called profiled parameters). In this class are the sodium concentration of the dialysate solution, the bicarbonate concentration of the dialysate solution, KT/V, and the ultrafiltration rate.

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In the preferred embodiment, ~~parameters~~<sup>all</sup> profiled parameters are selectably displayed in the form of bar graphs on the display screen. Using sodium as an example, the Y-axis represents sodium concentrations in the range of 130 - 160 mEq/L. The X-axis represents the treatment period, broken down into fifteen minute intervals. Such a display is shown in FIG. 10.

The use of bar graphs to display profiled parameters is known in the art. The prior art fails, however, to provide a convenient manner by which data characterizing the profile curve may be entered into the machine. Typically, such data entry has been accomplished through a keypad on which data for each discrete time period is entered. However, this approach requires dozens of key presses and provides numerous opportunities for error.

In the preferred embodiment, in contrast, profiled parameters are entered by simply tracing the desired profile curve on the touch screen.

In more detail, programming of profiled parameters is performed as follows:

From the main touch screen display of FIG. 8, the user presses MENUS. The programming screen of FIG. 11 then appears, which includes along its right hand side buttons corresponding to the programming of sodium, bicarbonate, kT/V, and ultrafiltration. The parameter desired to be programmed is then selected by touching the corresponding button.

In response to this touch, the screen of FIG. 10 appears. If a profile has already been programmed, it is displayed in bar graph fashion on this screen. Otherwise, the graph is empty.

Before permitting the user to program the sodium profile, the machine first solicits the sodium value of the sodium concentrate being used. This data is entered on a pop-up keypad. If the treatment time was not earlier programmed, the machine also solicits this data by means of a pop-up keypad.



Alternatively, the user can touch the screen at discrete points on the desired profile curve. To program a linear increase in sodium from 140 to 160 mEq/L, for example, the user would touch the graph at 140 at the ordinate corresponding to the beginning of the treatment interval, and 160 at the ordinate corresponding to the end of the treatment interval. The computer would then fit a linearly increasing series of bars between these points.

After the desired profile curve has been entered, the ENTER button is pressed to set the program in the machine.

35 Displayed on the screen during this programming operation is a numeric data window in which the numeric counterpart to a particular bar may be displayed. When the curve is first traced, the computer displays in this window the numerical parameter corresponding to each bar as it is defined. After the profile has been programmed,

the numeric counterpart to any bar can be displayed by first touching a LOCK button that locks the curve, and then touching the bar in question.

As with other parameters, profiled parameters  
30 must also be Verified before they take effect.

After the above-detailed data profiling operations are completed, data corresponding to the programmed profile is stored in the computer's memory. Periodically, such as once every fifteen minutes, a timed interrupt in the system's software program causes the computer to poll this memory for the value of the programmed parameter for the next time interval (here

fifteen minutes). The physical parameter is adjusted accordingly using conventional adjustment mechanisms.

Once treatment has begun, the system only permits bar graph-bars corresponding to upcoming time intervals to be programmed. Bars corresponding to past time intervals reflect treatment history and cannot be changed. To readily distinguish past from future, the bars corresponding to each are displayed in different colors.

Additional details on sodium programming, as well as details of bicarbonate and ultrafiltration programming, are contained in Appendix D.

In all aspects of the interface, the user is guided from one touch to the next by a feature of the preferred embodiment wherein the button that the user is most likely to press next is highlighted. For example, when the machine is in Rinse mode and is nearing completion of these operations, the Self-Test button is highlighted, indicating that this is the next likely operation. Similarly, when the Self-Test operation is nearing completion, the Prime button is highlighted. By this arrangement, even novice users are easily guided through the machine's various phases of operations.

In addition to the above-described user interface, communications with the dialysis machine can also be effected by an RS-232C serial data interface 530 and by a data card.

Data cards (also known as memory cards or RAM cards) are known in the art, as represented by U.S. Patents 4,450,024, 4,575,127, 4,617,216, 4,648,189, 4,683,371, 4,745,268, 4,795,898, 4,816,654, 4,827,512, 4,829,169, and 4,896,027, the disclosures of which are incorporated herein by reference. In the preferred embodiment, a data card can be used both to load treatment parameters into the machine and to download logged patient parameters from the machine for therapy analysis.

Among the treatment parameters that can be provided to the machine by a data card are the ultrafiltration profile, the sodium profile, the

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treatment bicarbonate flow rate  
the dialysate profile, the blood pump flow rate, the  
treatment time, the desired ultrafiltration removal  
volume, the dialysate flow rate, the dialysate  
temperature, the blood pressure measurement schedule and  
5 alarms, and the heparin prescription.

Among the patient parameters that are logged by  
the machine and that can be downloaded to a memory card  
for later therapy analysis are: temporal data relating to  
dialysate temperature and conductivity (both of which are  
10 typically measured at several points in the fluid  
circuit), venous, arterial, dialysate, systolic and  
diastolic pressures, blood flow rate, total blood  
processed, ultrafiltration rate, total ultrafiltrate  
removed, the ultrafiltrate goal, and the machine states.

15 Additionally, the data card can convey to the  
machine certain codes that, when read by the machine,  
initiate special operations. These operations include  
calibration mode, technician mode, enabling the blood  
pressure monitoring function, modifying the parameters  
20 transmitted over the serial port for diagnostics, and  
others.

The card used in the preferred embodiment is  
commercially available from Micro Chip Technologies under  
the trademark ENVOY and provides 32K of data storage in  
25 EEPROM form. Similar cards are also available from  
Datakey.

When a card containing treatment parameters is  
read by the machine, the stored parameters do not  
immediately take effect. Instead, each is displayed on  
30 the screen and the operator is asked, through prompts that  
appear on the screen, to verify each individually. If a  
parameter is not verified, that aspect of machine  
operation is left unchanged. In the preferred embodiment,  
the parameters loaded from a memory card are displayed in  
35 their respective parameter windows and each is highlighted  
in sequence, with the system soliciting verification of  
the parameter in the highlighted window. In alternative

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embodiments are  
embodiments, a plurality of parameters are be displayed  
for verification as a group.

Returning now to FIG. 7, the computer system 500 that controls the user interface and other aspects of machine operations is built around an IBM-AT compatible motherboard 502 that includes an Intel 80286 microprocessor 504 and 256K of RAM 506 interconnected by an AT bus 508. Into expansion slots in this motherboard plug seven additional boards: a memory board 510, an RS-232 board 512 (which is dedicated to controlling a patient blood pressure monitor), an Input/Output system controller board 514, an ultrafiltration/proportioning system controller board 516, a blood pump system controller board 518, a touch screen interface board 520, and an EGA display adapter board 522.

The computer system has five primary responsibilities: (1) user interface (i.e., through the CRT display and the touch screen); (2) state machine control (i.e., rinse, prime, dialyze, etc.); (3) microcontroller communications; (4) conducting of self-tests; and (5) calibrations. These functions are carried out by the AT-computer in conjunction with the above-listed expansion boards.

Turning now to a more detailed description of each component, the memory board 510 contains the firmware for the 80286 microprocessor. The memory board can hold up to 384K of read only memory (ROM) 524 and 8K of nonvolatile static random access memory (RAM) 526. Also included on the memory board is a memory interface 528, an RS-232C interface 530, and a time of day clock 532. The interface 528 is conventional and simply handles the addressing of memories 524 and 526. The RS-232C interface is for general purpose use (as opposed to the RS-232 interface 512 that is dedicated to use with a blood pressure monitor) and is typically used to remotely provide programming instructions to, and to interrogate patient treatment data from, the machine. The time of day clock 532 is used, inter alia, to time/date stamp patient



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The RS-232 board 512 permits computerized remote control of a patient blood pressure monitor. Suitable blood pressure monitors that are adapted for RS-232 control are available from Spacelabs of Hillsboro, Oregon.

5 The touch screen interface board 520 is commercially available as part number E271-400 from Elographics and is designed to operate with the E272-12 touch panel 501 that is used in the preferred embodiment. The function of the interface board 520 is to translate  
10 signals returned from the touch screen into a data format suitable for use by the 80286 microprocessor 504.

Terminate and stay resident software for driving the interface board 520 is available from Elographics.

15 The EGA display adapter card 522 is conventional and provides RGB signals to the CRT display 503.

The three microcontroller subsystems (the blood pump system 518, the ultrafiltration/proportioning system 516, and the I/O system 514) are particularly detailed in the following discussion.

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#### Blood Pump System

The blood pump controller 518 is built using an Intel 8040 microcontroller and is responsible for controlling or monitoring five subsystems. They are (1)  
25 the blood pump; (2) the blood pressure measurement (arterial, venous and expansion chamber); (3) heparin delivery; (4) level adjust; and (5) ambient temperature. The blood pump controller operates in conjunction with a blood pump power board (not shown) that controllably  
30 provides operating power to devices controlled by the blood pump controller.

In still more detail, the primary operation of the blood pump controller 518 is to supply power to the blood pump motor such that the pump head will turn and  
35 pump at a rate selected by the operator.

The blood pump controller system consists of the following major components:

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Description	Location
User parameter entry	Host controller
5 Software Speed Error Control	Blood Pmp Controller
Hardware Speed Error Control	BP Power Board
10 Optical speed sensor	On motor shaft
Motor Power Driver Circuitry	BP Power Board

The operator enters the desired blood pump rate information on the video screen (CRT) touch panel. The host controller (80286 microprocessor) converts this information to the appropriate motor rate which it then sends to the Blood Pump controller (8040) on the Blood Pump Controller board. The 8040 controller converts the motor rate information to an analog level, which is fed to a motor speed control IC (LM2917-8) on the Blood Pump Power board.

An optical speed sensor is mounted on the rear shaft of the blood pump motor, with an LED being positioned on one side of the shaft, and a photo transistor on the opposite side. The shaft has two holes drilled through it, with each hole being perpendicular to the shaft and to each other. This results in four optical pulses received per shaft revolution.

This tachometer signal is monitored by both the LM2917-8 and the 8040 controller. The LM2917-8 provides quick responding speed control by comparing the motor speed with the desired speed information from the 8040. The result of this comparison is an error signal which provides an input to the motor power driver circuit.

The motor power driver provides a +24 V pulse width modulated drive to the motor at a frequency of approximately 30 KHz. This drive is current limit protected, to prevent damage in the event of a stalled motor.

The 8040 compares the tachometer motor speed information with the desired speed commanded by the 80286



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LM2917-8

and reflects the level provided to the LM2917-8 accordingly. In this way the 8040 guarantees the ultimate accuracy of the pump, with the LM2917-8 circuit not requiring any calibration. In addition, the 8040 can monitor for control problems, such as under speed or over speed, which may result from failures in the LM2917-8 or motor drive circuitry.

The 8040 also monitors the motor speed independent of the tachometer signal using the motor's back EMF. Periodically (every 0.5 second) the motor drive is turned off for approximately 6 millisecond and the voltage at the motor terminals is measured. Though this does not result in as precise an indication as the tachometer signal, gross failures can be determined, such as when the tachometer signal is lost.

### Blood Pressure Measurement

The blood pressure measurements include the venous, arterial and expansion chamber (for Single Needle treatment) pressures. All three measurement systems include identical hardware. Each pressure is sensed by a SenSym SCX15 gauge sensing pressure transducer mounted to the Blood Pump Power board. Each transducer is connected to a differential amplifier designed to provide a measurement range from -400 to +600 mmHg. The output of each amplifier drives an A/D input channel of the Blood Pump Control system, at which point it is converted to a 10 bit digital value. The calibration of each of the pressure inputs is handled entirely in software, requiring that the design of each amplifier guarantee that its output remain within the A/D input range of 0 to +5 V over the input pressure range and over all component tolerances.

## Heparin Delivery

Heparin delivery is accomplished by stepping a stepper motor which rotates the pinion of a rack and pinion mechanism. The pinion moves the rack, and the

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mechanical

plunger

5 The gear fixture is such that the plunger of the heparin syringe moves the same distance. The stepper motor is controlled by the 8040 microcontroller located on the Blood Pump Controller board 518. When the operator enters a desired heparin rate in milliliters per hour (mL/h) via the front panel touch screen, the host 80286 microprocessor converts this information to the appropriate motor step rate and passes it to the Blood Pump microcontroller. The Blood Pump microcontroller 10 outputs a motor step rate logic signal to the Blood Pump Power board where the heparin motor power drive circuitry energizes the appropriate stepper motor coil.

The motor step rate logic signal from the Blood Pump microcontroller 518 is also input to the I/O 15 Controller board 8040 microcontroller 514. The I/O microcontroller monitors this signal to determine if the heparin motor is going the appropriate speed. If it determines that an overspeed condition exists, it disables the heparin motor via a disable line that goes to the 20 Blood Pump Power board.

There are two optical sensors to provide information about the state of the heparin pump. The disengage sensor detects when the front panel syringe holder arm is in the disengage position. The end-of- 25 stroke sensor detects when the pinion is raised up on the rack, which occurs when the gear teeth are not meshed. This is an indication of an overpressure condition. The Blood Pump microcontroller monitors the state of these sensors and passes the information to the host 80286 30 microprocessor.

#### Level Adjust

The level adjust system allows the operator to change the blood level in the arterial and venous drip 35 chambers. A level up and level down button exists for each drip chamber. The 8040 microcontroller on the Blood Pump Controller board 518 monitors the button positions. When a button is pressed, a valve selects that drip

motor

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Cabinet	Description	Location
	Fan	Base of cabinet
	Blood Pump Temperature IC	Blood Pump Power Board
	Misc I/O Temperature IC	Misc I/O Electronics Pwr Bd.
5	Software Fan Control	Host controller
	Cabinet Fan Drive	Blood Pump Power Board

The two LM35DZ temperature ICs are located on the Blood Pump and Misc I/O Electronics power boards. This IC outputs a voltage linear with temperature in °C (10.0 mV/°C). These temperature readings are input to the fan control software.

The fan control software always responds to the higher of the two temperatures. Typical values are as follows. At 46°C the fan turns on in the low speed mode and at 48°C it turns on in the high speed mode. There is a 2°C of hysteresis at these threshold temperatures, i.e., the fan returns to low speed at 46°C and turns off at 44°C. In addition, at 60°C a cabinet temperature alarm occurs that results in the machine shutdown state.

The fan power driver is located on the Blood Pump Power board. A motor rate signal from the Blood Pump Controller board determines the duty cycle of a 30 KHz pulse width modulated signal. This signal is input into a passive filter to provide a DC signal to the motor.

#### UF/Proportioning Control System

The ultrafiltration/proportioning (UF/PROP) controller 516 is built using an Intel 8040 microcontroller and is responsible for controlling the systems associated with ultrafiltration and dialysate preparation. This controller operates in conjunction with an ultrafiltration/ proportioning power card (not shown) that controllably provides operating power to devices controlled by the ultrafiltration/proportioning controller. Six subsystems are controlled or monitored by the UF/Proportioning controller 516. They are:

- 

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項目	単位	数量	金額	備考
1. 雑費	円	100	100	
2. 雑費	円	100	100	
3. 雑費	円	100	100	
4. 雑費	円	100	100	
5. 雑費	円	100	100	
6. 雑費	円	100	100	
7. 雑費	円	100	100	
8. 雑費	円	100	100	
9. 雑費	円	100	100	
10. 雑費	円	100	100	
11. 雑費	円	100	100	
12. 雑費	円	100	100	
13. 雑費	円	100	100	
14. 雑費	円	100	100	
15. 雑費	円	100	100	
16. 雑費	円	100	100	
17. 雑費	円	100	100	
18. 雑費	円	100	100	
19. 雑費	円	100	100	
20. 雑費	円	100	100	
21. 雑費	円	100	100	
22. 雑費	円	100	100	
23. 雑費	円	100	100	
24. 雑費	円	100	100	
25. 雑費	円	100	100	
26. 雑費	円	100	100	
27. 雑費	円	100	100	
28. 雑費	円	100	100	
29. 雑費	円	100	100	
30. 雑費	円	100	100	
31. 雑費	円	100	100	
32. 雑費	円	100	100	
33. 雑費	円	100	100	
34. 雑費	円	100	100	
35. 雑費	円	100	100	
36. 雑費	円	100	100	
37. 雑費	円	100	100	
38. 雑費	円	100	100	
39. 雑費	円	100	100	
40. 雑費	円	100	100	
41. 雑費	円	100	100	
42. 雑費	円	100	100	
43. 雑費	円	100	100	
44. 雑費	円	100	100	
45. 雑費	円	100	100	
46. 雑費	円	100	100	
47. 雑費	円	100	100	
48. 雑費	円	100	100	
49. 雑費	円	100	100	
50. 雑費	円	100	100	
51. 雑費	円	100	100	
52. 雑費	円	100	100	
53. 雑費	円	100	100	
54. 雑費	円	100	100	
55. 雑費	円	100	100	
56. 雑費	円	100	100	
57. 雑費	円	100	100	
58. 雑費	円	100	100	
59. 雑費	円	100	100	
60. 雑費	円	100	100	
61. 雑費	円	100	100	
62. 雑費	円	100	100	
63. 雑費	円	100	100	
64. 雑費	円	100	100	
65. 雑費	円	100	100	
66. 雑費	円	100	100	
67. 雑費	円	100	100	
68. 雑費	円	100	100	
69. 雑費	円	100	100	
70. 雑費	円	100	100	
71. 雑費	円	100	100	
72. 雑費	円	100	100	
73. 雑費	円	100	100	
74. 雑費	円	100	100	
75. 雑費	円	100	100	
76. 雑費	円	100	100	
77. 雑費	円	100	100	
78. 雑費	円	100	100	
79. 雑費	円	100	100	
80. 雑費	円	100	100	
81. 雑費	円	100	100	
82. 雑費	円	100	100	
83. 雑費	円	100		

The UF/PROP system 516 controls the

5 flow rate, and the "B" concentrate flow rate.

The "A" and "B" concentrate pumps (items 22 and 40, respectively, in ~~Fig. 1A and 1B~~ <sup>FIGS. 1A and 1B</sup>) are stepper-motor driven (each by a cam/follower) diaphragm pumps which deliver a calibrated volume of concentrate per stepper motor

10 revolution. Their flow rates are controlled by  
controlling the speed of the stepper motors. The  
concentrate pumps are unidirectional and utilize the  
proper actuation of a three-way valve for their intake and  
output pumping strokes. The intake stroke is synchronized  
15 by a signal that is generated by an optical interrupter  
sensor which senses a pin mounted on the cam of the pump  
assembly. Further details pertaining to the "A" and "B"  
concentrate pumps are described hereinbelow.

The UF/PROP controller 516 utilizes the fact that the stepper motors require 200 motor steps per revolution (between each synchronization pulse) to check the concentrate pumps for stepping errors. If late or early synchronization pulses are received then the associated error conditions are reported on the screen during the Technician Mode of the machine (further details provided hereinbelow).

During the Rinse Mode, the host determines the concentrate treatment mode based on the "A" and "B" rinse port interlock information (further details provided hereinbelow). If the "B" concentrate line (FIG. 1B, item 104) is not coupled to the "B" rinse port (FIG. 1A, item 30), a bicarbonate treatment is initiated by setting the proportioning ratios and the conductivity alarm limits appropriately. Conversely, if the "B" concentrate line is coupled to the "B" rinse port, an acetate treatment is initiated (further details provided hereinbelow). Using the dialysate flow rate and the proportioning ratios, the host determines the associated concentrate flow rates and



### UF Removal Control

C 5 The UF/PROP system 516 controls the UF removal rate by controlling the time between the switching of the UF flow meter valves (FIG. 4, items 142-149). The UF/PROP system controls the accumulated UF volume by counting the number of UF flow meter strokes.

10 Since the UF flow meter volume is calibrated (measured) in the Calibration Mode, the rate which the host (80286 microprocessor) passes to the UF/PROP controller (number of seconds between valve switches) is scaled so that the user-entered UF removal rate is achieved.

15 In the same way, the user-entered UF removal volume is scaled by the UF flow meter's stroke volume to a number of UF meter strokes. The host passes the number of UF meter strokes to the UF/PROP controller. The UF/PROP controller will then switch the UF flow meter valves and decrement the stroke number, at the desired rate, as long as the stroke number is greater than zero. The host can then calculate the UF removal volume accumulated by subtracting the number of UF flow meter strokes remaining, scaled by the stroke volume, from the operator-entered desired UF removal volume. The accumulated volume is displayed during the Dialyze Mode. This value remains during the Rinse Mode and is cleared upon the entry of the Self Test Mode.

20 In Rinse, the UF removal rate is 3.6 L/h and the video screen indicates no UF volume accumulated. During the Self Test Mode, no UF removal occurs except during specific self tests performed by the machine (no UF volume is accumulated). In the Prime Mode, the UF removal rate is set by the operator and is no greater than 0.5 L/h (no UF volume is accumulated). During the Dialyze Mode, the UF removal rate is set by the operator and is limited to between 0.1 and 4.00 L/h. For UF removal to occur in the Dialyze Mode the following conditions must be met:



rate

2. The blood pump is pumping.
3. The target UF volume has not been reached.

## C

15 The UF/PROP system measures conductivity at two  
locations (conductivity probes) in the hydraulic circuit  
using alternating-current resistance measurements between  
each of the conductivity probes' electrode pairs. The two  
flow path locations are at the "A" conductivity probe  
20 (FIG. 1A, item 38) and the "B" conductivity probe (FIG. 1B,  
item 46).

One electrode of each of the probes is stimulated with a 1 kHz ac voltage while the other is held at virtual ground (current sense electrode). Two voltages are produced by the resistance measurement circuit. The ratio of the voltages is proportional to the resistance of the respective probe. The resistance of the probes has been modeled as a function of temperature and conductivity. Since each of the conductivity probes contains a thermistor, the temperature at each of the probes is known. Using the model that was derived for the probes, the temperature measured at the probes, and the resistance measured at the probes the conductivity is calculated.

Each conductivity probe is calibrated during the Calibration Mode, at which time the resistance of each probe is measured at a known conductivity and temperature (by the use of an external reference meter) for the

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storing resistance in  
of the probe's base resistance the relationship described previously.

The UF/PROP system 516 generates alarms from the measured conductivities at the "A" and "B" probes. Since these conductivity alarms are used to verify the proportioning ratios, the alarms are generated by testing the "A" conductivity and the "B" portion of the total conductivity ("B" portion = "B" conductivity - "A" conductivity). The alarm limits are determined from the concentrate treatment mode and are stored in the UF/PROP controller by the host. Therefore only during a bicarbonate dialysis treatment would the host store a non-zero expected "B" conductivity portion.

The host determines the concentrate treatment mode during the Rinse Mode by reading the "A" and "B" rinse port interlock information. If the "B" concentrate line is not on the "B" rinse port, a bicarbonate treatment is initiated by setting the proportioning ratios and the conductivity alarm limits appropriately. Conversely, if the "B" concentrate line is coupled to the "B" rinse port, an acetate treatment is initiated. Upon exiting the Rinse Mode the concentrate treatment mode is set for the remainder of the dialysis treatment (concentrate treatment mode is only adjusted in the Rinse Mode).

#### Temperature Monitoring

The UF/PROP system 516 measures the dialysate temperature at three locations in the fluid path. The first location is directly after the heater (FIG. 1A, item 18) and this thermistor, the heater thermistor (FIG. 1A, item 20), is used for the primary temperature control feedback. The next two thermistors (FIGS. 1A and 1B, items 110 and 124) are contained in the "A" and "B" conductivity probes (FIG. 1, items 38 and 46, respectively). These temperatures are used to temperature-compensate the "A" and "B" conductivity measurements. The "B" conductivity temperature is also used to generate a backup high temperature alarm.

31/6/01

$$T(^{\circ}\text{C}) = (3.77\text{V} - V_{\text{temp}})(12.73)(^{\circ}\text{C}/\text{V}) + 37^{\circ}\text{C}.$$

The temperature that is displayed on the video screen is measured at the primary ("dialysate") conductivity probe, located just before the bypass valve (see FIG. 2), by the I/O controller.

Nine subsystems are controlled or monitored by the I/O control system 514. They are:

- 30
  - Air detector
  - Blood leak detector
  - Dialysate pressure monitor
  - Heparin pump overspeed monitor
  - Bypass system and flow sensor
- 35
  - Conductivity monitor
  - Temperature monitor
  - Line clamp
  - Power fail alarm

### Air Detector

The air detector assembly utilizes a set of 2 MHz piezo crystals. One crystal functions as an ultrasonic transmitter and the second crystal functions as a receiver. The transmitter and receiver are housed in separate but identical assemblies. There is a distance of 0.20 inch between these assemblies into which the venous blood line is placed during dialysis. The emitter is driven by a 2 MHz squarewave that is derived from a crystal oscillator located on an I/O Electrical Power board 536 that is connected to the I/O controller 514 by a ribbon cable. When there is fluid in the blood line between the crystal assemblies, the 2 MHz signal is coupled to the detector assembly. The return signal from the detector assembly is amplified and rectified by two independent circuits also located on the I/O Electrical Power board 536. These dc output levels are monitored using two different methods. The first method is the software generated alarm and the second is the hardware generated alarm.

### Software Alarm Detection (Primary Alarm)

One output is fed from the I/O Electrical Power board 536 to an A to D converter and read by the 8040 microcontroller on the I/O Controller board 514. This value is averaged over a 400 msec time period and reduced by multiplying it by 15/16 and subtracting 50 mV (for noise immunity). This new value is then converted back to an analog level to be used as an alarm limit. This software generated limit is compared to the rectified dc signal from the detector. The output state of this comparator is monitored by the on-board 8040. When the unaveraged signal falls below the software generated limit for longer than a calibratable time period, an alarm occurs. Sensitivity of the software alarm is 10 microlitres at 300 mL/min blood flow.

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Hardware Alarm Detection (Secondary Alarm)

The hardware alarm is redundant to the software generated alarm. This alarm uses two comparators on the I/O Electrical Power board 536. One comparator looks for a minimum dc level from the rectified detector signal which guarantees the presence of fluid in the venous tubing. The second comparator is ac-coupled to react to a large air bubble in the tubing. Sensitivity of this detector is approximately 300 microlitres at 300 mL/min blood flow. Both comparator outputs are wire OR'd together so that either comparator will generate an alarm.

## Blood Leak Detector

The detector assembly consists of a high-efficiency green LED and a photocell. These components are installed into a housing through which spent dialysate passes. Both of these components connect to the I/O Hydraulic Power board. The LED is connected to a voltage-to-current converter on an I/O Hydraulic Power board 534 (which is also connected to the I/O controller 514 by a ribbon cable). The input to this circuitry comes from the I/O Controller board 514. The photocell is tied to the +5 V reference supply through a 750k ohm resistor. This provides a voltage divider which is monitored on the I/O Controller board.

The current through the LED is adjustable and controlled via a D to A output from the I/O Controller board. The light intensity of the LED is adjusted to illuminate the photocell to a point where its resistance is below the alarm threshold. During a blood leak, the presence of blood in the housing attenuates the light striking the photocell which causes an increase in both the photocell resistance and voltage. The increase in voltage (monitored by the microcontroller on the I/O controller board) results in a blood-leak alarm.

Further details on the blood-leak detector are provided hereinbelow.

[illegible]

## Dialysate Pressure Monitor

The dialysate pressure is sensed by a resistive bridge pressure transducer (FIG. 1, item 64) located just upstream of the dialyzer. The transducer is connected to a differential amplifier circuit on the I/O Hydraulics Power board 534 designed to provide a measurement from -400 to +500 mmHg. The differential amplifier circuit also has an offset input that comes from a software calibratable variable, DAC\_OFFSET. The output of the amplifier drives an A/D input channel of the I/O Controller system, at which point it is converted to a 10 bit digital value. The calibration of the pressure input is handled entirely in the software, requiring that the design of the amplifier guarantee that the output remains within the A/D input range of 0 to +5 V over the input pressure range and over all component tolerances.

## Heparin Pump Overspeed Monitor

To ensure that the heparin pump does not exceed its set speed, the I/O controller board software monitors a clock signal from the Blood Pump Controller board that is equivalent to 1/4th the heparin pump step rate. In the event that a heparin pump overspeed occurs, the I/O controller board disables the heparin pump via a hardware line that goes to the Blood Pump Power board and notifies the host of the alarm.

30 To determine if the heparin pump is running at the correct speed, the time required for ten clock signals to occur is measured (and stored in variable HEPTIMER) and compared against a minimum time period that is set by the host (HP\_P\_MIN). If the measured period is less than the host set limit, a normal-speed alarm occurs. The host is notified of the normal-speed alarm and the heparin pump is disabled via the hardware line to the Blood Pump Power board.

When the heparin pump rate changes, the host resets the minimum time period, HP\_P\_MIN, and the I/O controller waits for the first clock signal to restart the

The I/O controller board 514 also monitors the total amount of heparin delivered in the high-speed bolus mode. When it receives clock signals at a rate faster than a predetermined speed, it assumes the pump is operating in the high-speed mode. It has a high-speed counter, H\_SPD\_CNTR, that is set by the host. If more high-speed counts occur than are in the counter, a high speed alarm occurs. The host is notified of the high-speed alarm and the heparin pump is disabled via the hardware line to the Blood Pump Power board.

### Bypass System and Flow Sensor

The bypass mode is initiated when a primary dialysate alarm is detected by the I/O Controller board, when a redundant dialysate alarm is detected by the UF/PROP Controller board 516, when the host requests bypass, or when the manual bypass button is pushed.

The bypass valve (FIG. 18, item 66) is in the bypass position when deenergized. It is driven from the nominal +24 V supply with a straight on/off transistor control on the I/O Hydraulics Power board.

To verify that there is not a failure in the bypass system, a flow sensor (FIG. 1A, item 62) located upstream of the dialyzer and just downstream of the bypass valve checks for flow. If flow exists during bypass, a Bypass Fail Alarm is triggered and the machine is put in the safe, nonfunctional, Shutdown state. If there is no flow when not in the bypass mode, a No Flow alarm is generated. (Further details on the flow sensor are provided hereinbelow.)

This flow sensor consists of two thermistors.

35 The first is a reference thermistor used to determine the fluid temperature. The second thermistor uses thermal dilution to sense the fluid flow. The voltage outputs from the thermistors on the I/O Hydraulics Power board 534

5 divider guarantees that the output remains within the A/D input range of 0 to +5 V over the input temperature/flow range and over all component tolerances.

C 10

15 signal is sent to the conductivity probe and a monitor circuit. Both the monitor circuit and the return signal are rectified and filtered. These dc values are routed to I/O Controller board 514 along with the temperature signal.

25 displayed on the CRT as the conductivity in milliSiemens  
per centimeter (mS/cm).

22

35 value is outside preset alarm limits, a bypass condition  
and an audio alarm occur.

The thermistor is wired to a resistor divider network on the I/O hydraulic board. The output of this



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divider

divider network is sent to the Miscellaneous I/O controller board 514 where it is monitored by the on-board 8040 microcontroller via an A-to-D converter network. From this information, the controller calculates the temperature using offset and gain parameters stored in the host from the calibration. Calibration of the temperature measurement is a two-point procedure done at 30 and 40°C.

10

#### Line Clamp

The line clamp opens with a solenoid and clamps with a spring return. When the solenoid is not energized, the spring pushes the plunger away from the solenoid. This causes the plunger to clamp the blood tubing. When the solenoid is energized, it pulls the plunger in with enough force to overcome the spring force. This unclamps the blood tubing. In the event of a power failure, the solenoid is de-energized causing the blood line to be clamped.

20

The solenoid is controlled by the line clamp board. On the line clamp board is a pulse-width modulated current controller. This circuit applies sufficient current to the line clamp solenoid to pull in the plunger. After pull in, the controller ramps the current down to a level capable of holding the line clamp open. This cut-back in current reduces the temperature of the solenoid, resulting in a more reliable device. Also located on the line clamp board, is a quick-release circuit which helps dissipate the power stored in the solenoid. The result of this circuitry is a quicker and more repeatable clamp time over the life of the machine.

30

Control for the line clamp comes from the Miscellaneous I/O controller board 514 via the I/O power board 536. The control signal for clamp and unclamp is optically coupled on the line clamp board. This provides electrical isolation between the high voltage used to operate the line clamp and the low voltage used for the control signals from the microprocessor.

35

Power Fail Alarm

The power-fail alarm circuitry is located on the Misc I/O Electrical Power board 536, and includes a CMOS power state flip flop powered by a 1 Farad (F) capacitor. The flip flop, which can be toggled by either the front panel power button or the 80286 system controller, provides the following functions:

- 10                     • Whenever power is not supplied to the machine (i.e., when the +5 V supply is off) and the flip flop is in the on state, power is supplied from the 1 F capacitor to the audio alarm device. Whenever power is  
15                     supplied to the machine, the flip flop's output state is ready by the 80286, which provides indication of the intended machine power state. Also, when the flip flop is in  
20                     the on state, power is supplied to the front panel power switch LED.
- The first function listed above results in the power fail alarm. The alarm occurs  
25                     either if the machine loses power while it is running, or if the front panel power button is pressed "on" when there is no power supplied to the machine. The alarm  
30                     can be silenced by toggling the flip flop off via pressing "off" the front panel power button.

Additional details of the preferred computer system 500 are provided, inter alia, in Appendix C.

Reference has been made to five appendices  
35 (A - E) which form part of the specification hereof and which further detail certain aspects of the preferred embodiment.

Sensor  
Bypass Valve Flow Sensor

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The dialysis machine of the present invention includes a bypass valve flow sensor which is utilized to confirm that dialysate flow to the dialyzer is completely interrupted during bypass. The bypass valve flow sensor comprises a first thermistor 202 and a second thermistor 204, as shown schematically in FIG. 2. FIG. 2 also shows in simplified schematic form the flow equalizer 54, the bypass valve 166, and a dialyzer 208. The first and second thermistors 202, 204 are of a negative-temperature-coefficient (NTC) type known in the art. The first, or "sensing," thermistor 202 is energized with a 20 mA constant current while the second, or "reference," thermistor 204 is driven with a negligibly small current.

The electrical resistance of both thermistors 202, 204 is measured using electronic circuitry (not shown). The resistance  $R(T)$  of each thermistor 202, 204 at a given temperature  $T$  is determined by the following relationship:

$$R(T) = (K_1) \cdot \exp(-K_2 \cdot T)$$

where  $K_1$  and  $K_2$  are constants. Hence, the thermistor resistance is a function of its temperature.

Since the electrical power input to the reference thermistor 204 is negligibly small, the temperature of the reference thermistor 204 will be substantially equal to that of the liquid surrounding it, whether flowing or not, at all times. The sensing thermistor 202, on the other hand, is powered by a substantial constant current. Hence, the sensing thermistor 202 will undergo appreciable self-heating. During conditions of no dialysate flow past the thermistors 202, 204, such as during bypass, the temperature of the reference thermistor 204 will be equal to the temperature of the dialysate surrounding the reference thermistor 204. However, the no-flow temperature of the sensing thermistor 202, as a result of self-heating, will be substantially greater than the

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temperature thermistor 204  
temperature of the reference thermistor 204. During  
conditions when dialysate is flowing past the thermistors  
202, 204, the temperature of the reference thermistor 204  
will, again, be equal to the temperature of the dialysate.  
5 The temperature of the sensing thermistor 202, while  
greater than that of the reference thermistor 204, will be  
somewhat lower than the temperature thereof would  
otherwise be during no-flow conditions. This is because  
dialysate flowing past the sensing thermistor 202 will  
10 conduct a portion of the self-heating energy away from the  
thermistor 202, thereby lowering the temperature of the  
thermistor 202. The bypass flow sensor can detect flow as  
low as about 3 mL/min.

Since the sensing thermistor 202 is driven with a  
15 constant-current source, the amount of power input into  
the thermistor 202 is limited according to the  
relationship  $P = I^2 R$ . As a result, the ultimate self-  
heating temperature achievable by the sensing thermistor  
202 will self-limit, thereby protecting the sensing  
20 thermistor 202 from a damaging thermal runaway condition.

The two thermistors 202, 204 are calibrated by  
measuring the electrical resistance across them  
individually under conditions of no dialysate flow at both  
30 and 40°C. A mathematical relationship is utilized  
25 during calibration which equates the resistance of the  
sensing thermistor 202 and the resistance of the reference  
thermistor 204 at any temperature between 30 and 40°C. If  
 $R_h(t)$  represents the sensing thermistor resistance at  
 $T = t$ , and  $R_r(t)$  represents the reference thermistor  
30 resistance at  $T = t$ , then, at no dialysate flow,  
 $R_h(t) = A \cdot R_r(t) + B$ , where A and B are calibration  
constants determined by the equations shown below (since  
 $R_h(30)$ ,  $R_h(40)$ ,  $R_r(30)$ , and  $R_r(40)$  are measured during  
calibration):

35

$$R_h(30) = A \cdot R_r(30) + B$$

$$R_h(40) = A \cdot R_r(40) + B$$

Hence, if the thermistor resistances are equal, then the electronic circuitry (not shown) coupled to the thermistors 202, 204 recognizes such equal resistance as indicating a "no dialysate flow" condition. However, if  
5 the resistances of the first and second thermistors 202, 204 are not equal, which occurs when any dialysate flow (greater than about 3 mL/min) is passing by the first and second thermistors 202, 204, the electronic circuitry recognizes a "dialysate flow" condition. Therefore,  
10 whenever the machine is in bypass, if the electronic circuitry senses that the resistances across the first and second thermistors 202, 204 is unequal, indicating flow, the machine will trigger an alarm condition to notify the operator of failure of the bypass valve 66.

15 The advantage of the bypass valve flow sensor 62 as described hereinabove is that it enables the dialysate bypass valve 66 to be tested functionally, i.e., via a determination of whether or not the bypass valve 66 actually shut off the flow of dialysate to the dialyzer  
20 208. This is the first known use of such a flow sensor in a hemodialysis machine. Other bypass valve sensors known in the relevant art merely test whether or not, for example, the bypass valve has been energized. One example of such a mechanism is a sensor that determines whether or  
25 not a solenoid controlling the valve has shifted position in response to application of current thereto. In the present invention, in contrast, the bypass valve flow sensor verifies that the bypass valve 66 has actually seated properly.

30 Further details and engineering data pertaining to the bypass valve flow sensor can be found in Appendix A, pp. ET 52 - ET 57 ("Flow Sensing"), ET 75 ("Bypass Fail Alarm"), Hydraulic Theory 9 ("Flow Sensor" and "Bypass Valve"), EC 13 ("Bypass Fail Detection"), and EA 11  
35 ("Bypass System and Flow Sensor").

46

No-Ultrafiltration-During-Bypass Sensor

C This feature, shown schematically as item 70 in FIGS. 1 and 2, utilizes a first and a second thermistor 210, 212 in a manner similar to the bypass valve flow sensor 62 discussed above. The first and second thermistors 210, 212 are exposed to dialysate flowing through conduit 174 just downstream of the dialyzer 208 but upstream of the bypass line 166.

This feature 70 is utilized during automatic testing of machine functions, as controlled by the machine's microprocessor. During such a test, dialysate flow is bypassed from the dialyzer 208. The flow equalizer 54 volumetrically matches the volume of dialysate that would ordinarily enter the dialysate compartment (not shown) of the dialyzer 208 with the volume of dialysate exiting the dialyzer 208. During bypass, the volume of dialysate passing through the bypass valve 66 and bypass line 166 is equal to the volume passing back through the flow equalizer 54 via line 158. Since the UF line 178 is occluded by the UF flow meter 76, any dialysate flow past the first and second thermistors 210, 212 in either direction must be due to dialysate flow passing through the dialyzer membrane (not shown) into the blood compartment (not shown) thereof or from the blood compartment thereof into the dialysate compartment thereof. If such flow is detected, the machine triggers an operator alarm.

Further details and engineering data pertaining to the no-UF-during-bypass sensor can be found in Appendix A, pp. ET 52 - ET 57 ("Flow Sensing"), and Hydraulic Theory 10 ("Flow Sensor").

Automatic Testing of Ultrafiltration Function

This feature is utilized during automatic testing of machine functions that occurs before the machine is used for patient treatment. This automatic test is controlled by the machine's microprocessor along with other self-test routines. One example of when

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ultrafiltration

automatically

ultrafiltration-function testing is automatically engaged is when the machine is in rinse and producing dialysate without any prevailing dialysate alarms such as temperature and conductivity. A complete self-test routine begins when the operator touches the "test" button on the touch screen before beginning a dialysis treatment. (See Appendix A, pp. Operation 3 (Step 10).)

C In order to test the ultrafiltration function, the dialysate lines 174, 206 (FIGS. 1<sup>A</sup> and 2) must be connected together, enabling dialysate to circulate therethrough without having to use a dialyzer. Because a dialyzer is not used, the flow equalizer 54 discharges a volume of dialysate into line 206 that is substantially equal to the volume of dialysate passing through line 174. Hence, a volumetrically closed loop is formed wherein dialysate exits the flow equalizer 54 through the outlets 156 thereof, passes through lines 206 and 174 coupled together, and reenters the flow equalizer 54 through the inlets 154 thereof. Included in this closed loop is the UF flow meter 76. The UF flow meter 76 permits a discrete volume of fluid to be removed from the closed loop. Also included in the closed loop is the dialysate pressure transducer 64.

To perform the test, the UF flow meter 76 removes about 3 mL of dialysate from the closed loop. This removal of 3 mL is sufficient to lower the dialysate pressure measured at the transducer 64 by about 200 to 300 mmHg. If there are no leaks in the closed loop, this lowered pressure will remain substantially constant. The machine will monitor the depressed dialysate pressure for about 30 seconds during which the pressure must remain within a  $\pm 50$  mmHg limit of the initial low value. If the pressure rises and passes a limit, the machine will trigger an operator alarm.

Further pertinent details concerning this feature and the UF flow meter can be found in Appendix A, pp. EA 7 ("UF Removal Control"), EC 25 - EC 26 ("UF Protective System"), EC 29 - EC 30 ("UF Test"), M 6 ("Flow

Equalizer"), M 9 ("UF Removal Flowmeter"), M 17 - M 19 ("Dialysate Flow Control System Performance"), and Hydraulic Theory 7 ("Flow Equalizer").

5           Automatic Setting of Proportioning Mode  
              Based Upon Connection of Concentrate Lines

C           As described hereinabove, the concentrate rinse fittings, e.g., the "A" and "B" rinse fittings 28, 30, respectively (FIG. 1), are equipped with proximity sensors 10 which sense whether or not the corresponding concentrate lines 94, 104, respectively, are connected thereto. Such information regarding whether or not a concentrate line is coupled to a corresponding rinse fitting is utilized by the machine's microprocessor to set the correct 15 proportioning mode, e.g., acetate or bicarbonate dialysis.

              For example, during the machine's "dialyze" mode, if the machine's microprocessor receives a signal indicating that the "B" concentrate line 104 is coupled to the "B" rinse fitting 30, the machine will operate only 20 the "A" concentrate pump 22. If the "B" concentrate line 104 is not coupled to the "B" rinse fitting 30, the machine will operate both the "A" and "B" concentrate pumps 22, 40, respectively. See Appendix A, pp. EA 5 - EA 6 ("Proportioning Control"), and EA 7 - EA 8 25 ("Conductivity Monitoring").

              Such connections of the "A" and "B" concentrate lines 94, 104 also dictate the proportioning ratio of "A" concentrate. During acetate dialysis, the volumetric ratio of "A" concentrate to dialysate is 1:35. During 30 bicarbonate dialysis with Drake Willock brand concentrates, for example, the volumetric ratio of "A" concentrate to dialysate is 1:36.83. Hence, the machine automatically adjusts the pumping rate of the "A" concentrate pump 22 in response to whether or not the "B" 35 concentrate line 104 is coupled to the "B" rinse fitting 30.

              The proximity sensors are shown in FIGS. 3A and 3B. FIG. 3A is an isometric depiction of, for example,



the "A" and "B" rinse fittings 28, 30 situated on the right side 218 of the machine. (See Appendix A, pp. Components & Functions 11). On the annular surface 220, 222 of each rinse fitting is an angled depression 224, 226, respectively. As depicted in the right-side elevational view of the "A" rinse fitting 28 shown in FIG. 3B, beneath the angled depression 224 is a light-emitting diode (LED) 228 (shown schematically). A photosensor 230 of a type known in the art is also situated beneath the angled depression 224. The LED 228 is energized with a pulsatile signal in the kilohertz range (so as to not be fooled by 60 Hz illumination). The LED 228 and photosensor 230 are oriented such that light 232 from the LED 228 passes through a first face 234 of the angled depression 224, is reflected off an annular surface 236 of a connector 238 on the end of the "A" concentrate line 94, passes through a second face 240 of the angled depression 224 to be sensed by the photosensor 230.

So long as the photosensor 230 receives reflected light from the LED 228, the machine's microprocessor circuitry (not shown) "interprets" such a condition as indicating that the "A" concentrate line 94 is coupled to the "A" rinse fitting 28. If the light 232 does not reflect so as to impinge the LED 230, the microprocessor circuitry "interprets" such a condition as indicating that the "A" concentrate line 94 is not coupled to the "A" rinse fitting 28 but is coupled to, e.g., a supply of "A" concentrate.

#### Prediction of Dialysate Conductivity

The software controlling the operation of the machine's microprocessor includes a routine for predicting correct dialysate conductivity. Such predictions automatically reflect the particular brand of concentrate being used, since different groups of concentrate brands require different proportioning to yield a dialysate having a correct ionic strength and electrolytic profile.

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[illegible]

that the displayed conductivity value is correct, the machine will compare the displayed "actual" value with the "calculated" value. If the "calculated" value is different from the displayed value, the machine will

5 regard the displayed baseline value as correct since the operator "told" the machine that the displayed value is correct. The machine will also calculate the ratio of the displayed baseline value over the calculated baseline value and will multiply any subsequently determined

10 calculated value during the dialysis treatment by the ratio to obtain new "expected" conductivity values. For example, for variable sodium dialysis, the operator will program the variable sodium profile to be delivered to a patient over the course of the upcoming dialysis

15 treatment. Whenever the machine changes the sodium concentration during the course of treatment as programmed by the operator, which accordingly changes the dialysate conductivity, the machine will redetermine a "calculated" conductivity value and apply said ratio to determine a new

20 "expected" conductivity value. These expected conductivity values are used by the machine to calculate and set upper and lower conductivity alarm limits at  $\pm 5\%$  of the initial or adjusted "expected" conductivity value.

For Cobe brand bicarbonate concentrates, the

25 calculated baseline dialysate conductivity is determined by the following algorithm:

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$$\text{calculated conductivity in mS/cm} = [-.036 + 3.7 \times 10^{-5} ([\text{Na}^+] - 130)][\text{HCO}_3^-] + [14.37 + .101([\text{Na}^+] - 130)]$$

where the operator enters the baseline concentrations of sodium and bicarbonate using the touch screen.

For Drake Willock brand bicarbonate concentrates, the calculated baseline conductivity of bicarbonate

35 dialysate is determined by the following algorithm:

$$\text{calculated conductivity in mS/cm} = .1038[\text{Na}^+] - .54$$

where the operator enters the baseline concentration of sodium using the touch screen.

For all brands of acetate concentrates, the calculated baseline conductivity of acetate dialysate is determined by the following algorithm:

$$\text{calculated conductivity in mS/cm} = .0895[\text{Na}^+] + 1.41$$

where the operator enters the baseline concentration of sodium using the touch screen.

For bicarbonate dialysis, the machine will also automatically set alarm limits around the conductivity measured at the "A" conductivity probe 38 (FIG. 1A) in a similar manner. (During acetate dialysis, the conductivity at the "A" conductivity probe 38 is equal to the conductivity at the dialysate conductivity probe 60, so setting of alarm limits around the conductivity at the "A" conductivity probe is not necessary.) For bicarbonate dialysis, the machine "assumes" that the "A" concentrate is being proportioned properly (at the correct proportioning ratio), based upon the operator having verified that the displayed dialysate conductivity value is correct. The machine determines a baseline "calculated" conductivity at the "A" conductivity probe based on baseline sodium and bicarbonate concentrate information provided by the operator via the touch screen. The machine then calculates a ratio of the actual conductivity as measured at the "A" conductivity probe 38 over the calculated conductivity at the "A" conductivity probe. Then, whenever the machine changes the sodium concentration during the course of a dialysis treatment as programmed by the operator, the machine will determine a new calculated conductivity value and apply said ratio to determine a new "expected" conductivity value at the "A" conductivity probe.

For Cobe brand bicarbonate concentrates, the calculated baseline conductivity at the "A" conductivity probe is determined by the following algorithm:



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empty

condition at the start of the phase. In accordance with the above, it is preferable, for example, that the filling of the "post" compartment 134 reach end of stroke at the same instant as filling of the "pre" compartment 132 during a phase and that filling of the "post" compartment 136 reach end of stroke at the same instant as filling of the "pre" compartment 130 during a different phase. Such simultaneous reaching of end of stroke eliminates ultrafiltration inaccuracies that otherwise could result if the "pre" and "post" compartments (e.g., 130 and 136) being, say, filled during a phase are not filled at exactly the same rate.

Since valves 143, 144, 146, and 149 all turn on at the same instant that valves 142, 145, 147, and 148 turn off, and vice versa, and since each pair of compartments 130, 134 and 132, 136 have exactly the same volume, it is possible to have pairs of compartments (130, 136, and 134, 132) reach end of stroke at the same instant. However, assuming that each chamber 126, 128 has exactly the same flow restriction therethrough, achieving simultaneous end of stroke requires at least that pressures at the inlets 154 be matched and that pressures at the outlets 156 be matched.

To achieve such pressure matching, the inlets 154 are provided with an input pressure equalizer 52 and the outlets 156 are provided with an output pressure equalizer 56, as shown in FIG. 4. The input pressure equalizer 52 is comprised of a flexible diaphragm 246 separating first and second enclosed cavities 248, 250. A stem 252 is attached to the center of the diaphragm 246 and terminates with a flow-restricting element 254. The output pressure equalizer 56 is likewise comprised of a flexible diaphragm 256 separating first and second enclosed cavities 258, 260. Extending from the center of the diaphragm 256 on both sides thereof are stems 262, 264, each terminating with a flow-restricting element 266, 268.

Dialysate from the supply pump 42 flows unimpeded through the second cavity 250 on into a "pre" compartment

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of the flow equalizer 54. The first cavity 248 passes dialysate from the dialyzer to a "post" compartment of the flow equalizer 54. The first cavity 248 is also part of a loop including the dialysate pressure pump 72. This hydraulic configuration has been found to maintain identical pressures and therefore identical flow rates at the inlets 154 of the flow equalizer 54.

With respect to the output pressure equalizer 56, when the pressure is equal in both cavities 258, 260, the flow rates through each is identical. When the pressure, say, in the first cavity 258 exceeds that in the second cavity 260, the flow-restricting element 268 impedes flow into line 150, thereby increasing the pressure in the second cavity 260. This hydraulic configuration has been found to maintain identical pressures and therefore identical flow rates at the outlets 156 of the flow equalizer 54.

Therefore, since pressures and flow rates are identical as described above, both diaphragms 138, 140 (FIG. 8) come to end of stroke at the same time.

The time required to attain end of stroke can also be controlled. The dialysate flow rate is set by the operator using the touch screen. This flow rate determines the shift frequency of the valves 142-149. The higher the dialysate flow rate, the more frequently the valves 142-149 shift. However, a machine malfunction or occlusion of a hydraulic line could cause an excessive end-of-stroke time for one or both diaphragms 138, 140.

As discussed hereinabove, flow sensors 162, 164 (FIG. 8) are provided at the outlets 156 of the flow equalizer 54 for verifying when the diaphragms 138, 140 have reached end of stroke. When a diaphragm 138 or 140 has reached end of stroke, the corresponding flow sensor 162 or 164, respectively, sends a no-flow signal to the microprocessor. The flow sensors 162, 164 are each comprised of a reference and sensing thermistor (not shown) and work in a manner similar to the bypass valve flow sensor 62 and sensor 70 discussed hereinabove.

If the valves 142-149 receive a signal from the microprocessor to shift before the flow sensors 162, 164 have detected end of stroke, the valves are prevented by the microprocessor from shifting until the end-of-stroke signal(s) are received by the microprocessor. In the event of an excessively long end-of-stroke time, the microprocessor triggers an increase in the pumping rate of the supply pump 42 to speed up the time to end of stroke.

Controlling the end-of-stroke time not only increases the UF removal accuracy of the machine but also keeps dialysate flowing through the dialyzer as much as possible to maintain the desired osmotic gradient therein, and ensures accurate proportioning and mixing of concentrates with water to form dialysate.

Further details on this feature can be found in Appendix A, pp. EA 6 ("Flow Control"), ET 28 - ET 32 ("Dialysate Flow Control"), M 17 - M 19 ("Dialysate Flow Control System Performance"), and Hydraulic Theory 6-8 ("Input Pressure Equalizer," "Flow Equalizer," "Output Pressure Equalizer," "End of Stroke Sensors").

#### Timed Mode Initiate From Power-Off

The microprocessor programming as described herein can be conventionally implemented to accomplish a timed mode initiation from a power-off condition. As is known in the art, machine disinfection, rinsing, and "coming up" on concentrate and temperature to produce dialysate in a condition to begin treatment are burdensome tasks that typically must be performed before the start of a treatment day. In large clinics having multiple dialysis machines, performing these tasks manually can require a substantial expenditure of time and other personnel resources.

The electronics of the machine are continuously powered, even when the machine is "off," unless the mains switch has been turned off or unless the machine's power cord is unplugged. As a result, the programming is readily adapted to include use of the key pad display on



the touch screen by the operator to enter the desired time at which certain designated machine functions are automatically initiated. These functions include disinfection (such as heat-cleaning), rinsing, and beginning the production of dialysate at the desired temperature and ionic strength for dialysis treatment.

Preservation of Machine Parameters During Brief Power-Off

The hemodialysis machine of the present invention is provided with a battery back-up which preserves certain operational parameters previously entered by the operator in the event of a temporary power interruption (less than about 20 minutes). Upon restoration of power, the machine is in the stand-by mode.

All of the following parameters are saved in static RAM every 30 seconds or upon any major change in machine state. Upon restoration of power after less than 20 minutes after the last "time stamp" (time at which parameters were saved) by the machine, the following parameters are restored:

Temperature correction  
Accumulated UF volume removed  
Desired UF removal volume  
UF removal rate  
UF override flag  
Current machine state  
Previous machine state  
Self-test pass/fail flag  
Time stamp  
Prescribed dialysis time  
Elapsed treatment time  
Prescribed or elapsed treatment time display flag  
Manual or calculated UF rate display flag  
Heparin pump rate  
Accumulated blood  
Accumulated heparin  
Alarm window limits for conductivity,  
temperature, prescribed treatment time,  
heparin, etc.  
Profile settings for variable sodium and bicarbonate

Upon restoration of power, the "dialyze" mode can be restored by the operator touching the appropriate "button" on the touch screen.

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Drip-Chamber Level Adjusters

As is known in the art, hemodialysis treatment requires use of an extracorporeal blood-line set. Blood-line sets are available from a number of manufacturers in a variety of different configurations. Virtually all blood-line sets have at least a venous drip chamber. Usually, an arterial drip chamber is also included. The drip chambers serve several functions, including providing a means for removing air and foam from the extracorporeal blood before the blood is returned to the patient, and providing convenient sites at which extracorporeal arterial and venous blood pressure can be measured.

A portion of the extracorporeal blood-line set, including drip chambers, is normally fitted to the front of a hemodialysis machine in an orderly and convenient arrangement using special clips and the like. See Appendix A, pp. Components & Functions 4-5. Each drip chamber typically includes a short tubing segment terminated with a female fitting of a type known in the art as a Luer fitting. The female Luer is adapted for connection to a male Luer fitting on or near the front of the machine (see Appendix A, pp. Components & Functions 2-3), thereby providing the requisite connection of the drip chamber to a pressure-measuring component in the machine.

Drip chambers must be provided with a means for adjusting the blood level therein, particularly to ensure that the blood level does not drop so low in the drip chamber that air becomes re-entrained in the blood. Dialysis machines as currently known in the art require that the operator manually rotate one or more knobs on the machine to rotate a peristaltic pump coupled to the corresponding drip chamber. Such a manual operation has

proven to be a cumbersome annoying task, especially since the peristaltic pumps can be difficult to rotate.

The machine of the present invention overcomes this problem by providing, as shown schematically in FIG. 5, an electrically driven reversible positive-displacement pump such as a peristaltic pump 272 which replaces the hand-operated peristaltic pumps found on conventional hemodialysis machines. The peristaltic pump 272 is fitted with flexible tubing 274, one end 276 of which is open to the atmosphere. The opposite end 278 is coupled in parallel to an "arterial" valve 280 and a "venous" valve 282 coupled to an arterial drip chamber 284 and a venous drip chamber 286, respectively. The valves 280, 282 are preferably solenoid valves of a type known in the art. Each drip chamber 284, 286 is coupled via a corresponding Luer fitting 288, 290 to the corresponding valve 280, 282. Included upstream of each Luer fitting 288, 290 is a pressure-measuring device 292, 294, such as a pressure transducer, which communicates with the microprocessor (not shown).

On the front of the machine are arterial and venous "up" buttons 296, 298, respectively, and arterial and venous "down" buttons 300, 302, respectively, which control operation of the corresponding valves 280, 282 and the peristaltic pump 272. See Appendix A, pp. Components & Functions 2-3. For example, pressing the arterial "up" button 296 opens valve 280 and initiates rotation of the peristaltic pump 272 so as to raise the blood level in the arterial drip chamber 284. Pressing the arterial "down" button 300 opens valve 280 and initiates an opposite rotation of the peristaltic pump 272 so as to lower the blood level in the arterial drip chamber 284. The venous "up" and "down" buttons 298, 302 operate in the same way to control the blood level in the venous drip chamber 286.

Further details pertaining to this feature are in Appendix A, pp. EA 4 ("Level Adjust"), ET 11 - ET 12 ("Level Adjust"), and M 2 - M 3 ("Level Adjusters").

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Increasing Dialysate Flow Velocity Through the Dialyzer  
Without Increasing Dialysate Flow Rate

Most hemodialyzers currently in use are hollow-fiber types which generally have a more compact shape than parallel-plate or coil dialyzers used previously. Hollow-fiber dialyzers as known in the art typically comprise a bundle of fine hollow fibers, each fiber made of a semipermeable membrane material, encased in an outer cylindrical shell. The shell defines a space surrounding the fibers termed the "dialysate compartment" through which flows the dialysate prepared by a dialysis machine. The patient's blood is conducted through the lumens of the hollow fibers, propelled by a blood pump on the dialysis machine.

Clearance of metabolic solutes from the blood through the fiber membrane to the dialysate depends on a number of factors, including the osmotic gradient across the semipermeable membranes. The osmotic gradient is dependent on a number of factors including ionic strength and ionic profile of the dialysate, dialysate flow rate through the dialysate compartment, and flow dynamics of the dialysate as it flows through the dialysate compartment.

It is important that the dialysate flow rate be high enough to expose the fibers to a sufficient supply of fresh dialysate to effect satisfactory clearance of toxic solutes from the patient's blood at a satisfactory rate. Any dead spaces or areas of blockage in the dialysate compartment which are not exposed to a continuous supply of fresh dialysate will adversely affect clearance. Such dead spaces can be reduced by merely increasing the dialysate flow rate. However, increasing the dialysate flow rate also increases the rate at which expensive dialysate concentrates are consumed. Therefore, it is advantageous, especially with large dialyzers, to increase dialysate flow velocity through the dialysate compartment without necessitating a corresponding increase in net dialysate flow through the dialysate compartment.

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Most dialysis machines currently in use are capable of delivering only a fixed rate of dialysate flow, usually 500 mL/min. The blood-leak detectors on those machines operate with a detection sensitivity that is set at a fixed level and not changed during the course of treating a patient or even a series of patients. At a dialysate flow rate of 500 mL/min, many conventional blood-leak detectors are set to detect blood having a 25% hematocrit flowing at 0.35 mL/min into the dialysate.

The dialysis machine of the present invention is capable of delivering dialysate at flow rates ranging from 500 to 1000 mL/min, adjustable in 100 mL/min increments. At various dialysate flow rates, a fixed leak rate of blood from the patient will be diluted a different amount by the dialysate. Therefore, a blood-leak detector having a fixed sensitivity level enabling it to detect a small blood leak in dialysate flowing at 500 mL/min may not be able to detect the same blood leak in dialysate flowing at 1000 mL/min.

The dialysis machine of the present invention is provided with a blood-leak detector 78 employing a green LED 194 and a photosensor 196 (FIG. 19). (A green LED is used because of the strong absorbance of green light by red blood, yielding a greater contrast in the blood-leak detector between the presence and absence of blood.) The blood-leak detector has a sensitivity that is automatically adjusted in a proportional manner to sense a given leak rate of blood into dialysate having any dialysate flow rate between the 500 to 1000 mL/min adjustability range. Such automatic adjustment of the blood-leak detector sensitivity is performed by the microprocessor in response to the operator selecting a desired dialysate flow rate. The microprocessor adjusts the blood-leak detector sensitivity by altering the illumination level of the LED 194.

Further details on this feature can be found in Appendix A, pp. EA 10 ("Blood Leak Detector"), EC 20

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("Blood Leak Detector"), EC 29 ("Blood Leak Detector Test"), and ET 46 - ET 52 ("Blood Leak Detector").

Calibration Scheduler and Data Logger  
And Warning Message Logger

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The dialysis machine of the present invention has a technician-activatable "calibration" mode and is programmed to permit entry of calibration data, dates on which certain calibrations or adjustments are performed, and dates on which a particular dialysis center may desire to have certain calibrations or adjustments performed. Appendix A, pp. Preventive Maintenance 8-9. The machine also automatically logs warning messages that can be of substantial help to a technician servicing the machine.

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The calibration mode can be activated by turning on an internal calibration switch, as described in Appendix A, pp. Preventive Maintenance 7-8. When the calibrations are completed, the machine is returned to the operational mode by turning off the internal calibration switch, as described in Appendix A, pp. Preventive Maintenance 8, and restarting the machine using the mains power switch. Upon entering the calibration mode, the touch screen displays tables of various calibrations and makes provision for the operator to enter data or dates pertaining to any of the listed calibrations. These tables are illustrated in Appendix A, pp. Preventive Maintenance 8-9. Representative calibration instructions, including how to enter data, are provided in Appendix A, pp. Preventive Maintenance 9-20.

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The machine includes a number of component monitors which are used by the microprocessor to note and "record" incidents wherein the respective components experience an operational anomaly of interest to a machine technician. For example, the "A" and "B" proportioning pumps 22, 40 (FIG. 1) are each driven with a stepper motor 90, 114, respectively. The stepper motors 90, 114 utilize 200 "steps" per revolution of the motor shaft. Appendix A, pp. EA 5 - EA 6 ("Proportioning Control"). The stepper

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20 "Illegal qlen in BP_XMIT"
    "Blood Pump Low Speed"
    "BP Control Shutdown"
    "BP Command Error"
    "Blood Pump Overspeed Alarm"
    "Bld Pmp Overspeed Alarm"
25 "Illegal index in bp_xmit()"
    "Illegal index in bp_input()"
    "long timer error"

UF/PROP SYSTEM
30 "Too much time between EOS signals"
    "Early EOS detection"
    "UF SHUTDOWN"
    "UF Command Error"
    "UF Time scheduled Event Error"
35 "Unidentified Error in MISC_ERRFLG"
    "A Pump Noise"
    "A Pump Missed Steps"
    "B Pump Noise"
    "B Pump Missed Steps"
40 "C Pump Noise"

    "C Pump Missed Steps"
    "A temperature probe error"
    "B temperature probe error"

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